The PS test field, from left, the Adler Barbour CU-100, the Frigoboat Capri 35F, and the Sea Frost BD.

Fridge Chill-Off

Frigoboat's Capri 35F small box system squeezes past Adler Barbour and Sea Frost.

During the past few decades, a technical evolution has made the hardware that powers the refrigeration cycle more efficient and more reliable than ever. Today, almost all new cruisers and racers come with refrigeration, or it is near the top of the options list.

In the May 2007 issue of *Practical Sailor,* we looked at portable, 12-volt "plug and play" freezer-fridges, with the Norcold MRFT 60 and the Engel MT-35F leading the pack. Here, we review systems from three principal makers, Dometic Corp., Frigoboat, and Sea Frost. These are among the most popular ice-box conversion systems on the North American market today. Each is designed as a do-it-yourself kit that turns the ice box into a full-fledged refrigerator and/or small freezer.

All three manufacturers use Danfoss hermetically sealed compressors, devices that have been engineered to house a miniaturized drive motor and compressor inside a grapefruit-size air-tight tank. The evolution of the unit's DC controller eliminates the need for a conventional commutator and brush assembly, and two decades worth of improvements have significantly increased the system's efficiency. The result is an easy-to-install fridge for modest-sized sailboats with well-insulated ice boxes, and an easily expandable system (compressors can be piggy-backed) to suit larger boats.

DESIGN ORIGINS

The modern marine refrigeration system can be traced back to ice-cube guru Mike Adler, a cruising sailor who applied his engineering talents to a cause that any modern sailor can appreciate—developing a compact, efficient, and reliable alternative to ice.

Going against the prevailing trend of systems with high-capacity mechanical, engine-driven compressors, Adler staked his reputation on the compact Danfoss brushless 12-volt DC electric compressor. It didn't take long for Adler's system to attract converts. The German-engineered Danfoss compressor was not only reliable, it was truly the wave of the future, as advances in battery capacity and charging systems favored 12-volt systems.

The hermetically sealed electric compressor wasn't a new concept. It was introduced in 1926 by General Electric, and the AC version had dominated household refrigeration for many decades. What differentiates the Danfoss is that it eliminates the inefficient brush-and-commutator design of conventional DC motors. Using an external, solid-state controller and three-phase pulse technology to propel the motor, the Danfoss unit has improved efficiency and reliability.

Hermetic units, like their mechanical drive cousins, have pros and cons. The system's strongest attribute is its reliability, a factor that has no doubt contributed to the sagging demand for "Freon Jockeys," those mobile fridge-repair artists who once enjoyed superhero status on the cruising circuit.

The history of the system aboard *PS* Technical Editor Ralph Naranjo's Ericson 41 illustrates well the robustness of the early Adler Barbours. Naranjo installed an original Adler Barbour unit aboard his sloop, *Wind Shadow,* in 1982. He replaced the evaporator in 1990 and finally removed the unit in 2009 in order to long-term test some of the newer models. Not alone did the original unit perform exceptionally well; energy for its operation was generated by four ARCO M-55 solar panels that continue today to deliver the same current they delivered in 1982.

WHAT WE TESTED

The refrigeration systems *PS* selected for this comparison—the Waeco-Adler Barbour Cold Machine (CU-100) from Dometic Corp., the Frigoboat Capri 35F, and the Sea Frost BD—represent a good cross-section of what's on the conversion-kit market today.

Heir to Mike Adler's brainchild, the Cold Machine is a widely distributed production-boat standard. Its maker, Waeco, was acquired in 2007 by Dometic Corp., a Swedish-based multinational that oversees a huge line of marine products.

The Frigoboat system was developed by

Refrigeration 101

Most refrigeration systems use pumps to compress a gas into a liquid and harness the expansion process in order to transfer heat from one place to another. The process starts at the compressor, where a refrigerant gas is compressed and pumped through copper tubing. Downstream lies the condenser, which sheds heat resulting from compression.

The units we tested all used air-cooled condensers. Water is far more efficient than air at removing heat, but air-cooled units don't require the complexity and power requirements of additional pumps and plumbing. (Another water-cooled option is Frigoboat's keel cooler, which circulates refrigerant through a custom through-hull fitting. This requires no additional pump and makes sense for boats cruising in southern latitudes.) After the condenser, the refrigerant is pumped to either an expansion valve or capillary tube. These devices precisely meter flow into the evaporator, rapidly decreasing the refrigerant pressure.

The refrigerant transitions into a gas in the evaporator, where the cooling process (actually the removal of heat, measured in British Thermal Units) takes place. Due to their limited capacity, 12-volt DC hermetic compressors are almost always used with aluminum or stainless "direct" evaporators, in which the heat exchange occurs directly at the surface of a metal plate. In some designs, a holding plate filled with eutectic solution is used instead of an evaporator plate, and the solution serves as an intermediary for heat transfer.

The change in pressure at the evaporator plate initiates the final liquid-to-gas transformation, and during this change of state, heat in the box is absorbed by the refrigerant and conveyed out of the box, back to the compressor. Finally, the gas arrives at the suction side of the compressor and reenters the cooling cycle.

Cooling efficiency refers to how much energy is consumed in order to derive a given amount of cooling. Cooling capacity refers to how much heat energy can be removed in a given amount of time. Sound engineering principles dictate the right relationship between box size, evaporator or plate surface area, and the capacity of the compressor. Naturally, a large evaporator and a small compressor is a mismatch in capacity. Ideally, fridge run times of 50 percent or less should be the goal, but hot weather, warm beer, and lots of box opening can change the picture.

The Sea Frost features a stainless-steel evaporator plate (above left) built for durability. Though better at transferring heat, aluminum plates tend to wear out in eight to 10 years.

Veco SPA, a family-run company based in Italy that has specialized in marine refrigeration (and now air conditioning) for more than 25 years. The Sea Frost BD, the only U.S.-made unit in the review, comes from a relatively small but successful New Hampshire-based company that has been around for more than two decades. The company often gets good reviews from *PS* readers for its outstanding customer service.

All of these units are compact and easy to install, well suited for a do-it-yourself installation. The units run with a whisper-quiet whir and a faint, reassuring gurgle of refrigerant circulation. All use R-134A refrigerant, which replaced R-12 several years ago. They draw from 3 to 6.5 amps when operating. Their duty cycle, or percentage of time that they remain on, depends upon the climate, size of the box, insulation, and how the box is used.

Most manufacturers recommend picking a system with enough cooling capacity so that the compressor is running 50 percent of the time that the fridge is in use. The importance of efficiency is self-evident once you leave the dock. Even at a modest 2- to 3-amp-hour draw, the current consumption over a 24-hour period can add up to 48 to 72 amp-hours.

COLD MACHINE

Dometic carries on the tradition pioneered by Adler with a line that includes air- and water-cooled 12- and 24-volt DC hermetic units. We tested the CU-100. This system uses the BD50F Danfoss compressor, and testers found it to have approximately 25-percent more cooling capacity than the Danfoss BD35F compressor. The increase in capacity stems from a 25-percent larger displacement, but the BD50F compressor fits into the same shell as the BD35F, and all dimensions remain the same.

The current consumption and capacity vary according to box temp and the motor RPM selected, but along with the 25-percent increase in cooling capacity comes a power demand that's about 40-percent higher than the BD35F. This means that the BD50F tends to have a lower coefficient of performance (COP) than the BD35F, but there's more at stake than the numbers indicate. Efficiency is one factor, but it is equally important that the box and climate constraints are matched with the capacity of the unit. In this respect, choosing a reefer is a bit like selecting a car: The job at hand, rather than fuel efficiency, may define what is best for you. You don't want a Toyota Prius to do the work of a pickup.

On many boats, the box size, insulation efficiency, and the ambient conditions may best suit the smaller, more efficient BD35F system. But sometimes, even a small ice box may need high-capacity cooling due to poor insulation, brutally hot weather, or because hot can drinks are frequently being cycled into the box. These environmental and use

AS VALUE GUIDE 12-VOLT ICE BOX CONVERSION KITS

MAKE	DOMETIC ✓	FRIGOBOAT* ★	SEA FROST ✓
MODE	Adler Barbour Cold Machine	Capri 35F	BD
COMPRESSOR	Danfoss BD50F	Danfoss BD35F	Danfoss BD50F
EVAPORATOR	VD-152 aluminum bin	250B aluminum bin	12x17 SS plate
COOLING	Air	Air	Air
COMPRESSOR SIZE	11 x 10 x 8.5 inches	10 x 8.25 x 7.25 inches	14.5 x 5.25 x 7.75
60-40° TEMP. TEST / RPM SETTING	15.2 min. at 5.3A / Automatic (AEO)	19 min. at 2.9A / 2,000 RPM	24.25 min. at 6.3A / 3,500 RPM
40° CYCLE TEST (12 HOURS)	13.6 Ah	12.3 Ah (3,500 RPM) / 7.3 Ah (2,000 RPM)	14.2 Ah (3,500 RPM)
CAPACITY TEST *	3.8 hrs, 24.7 Ah	5.1 hrs, 20.6 Ah (3,500 RPM)	6.8 hrs. 18.6 Ah (3,500 RPM)
WARRANTY	Parts 2 years; labor 1 year	Compressor 5 years; electric 2 years; mechanical 1 year	1 year
PRICE/SOURCE	$1,440 / westmarine.com	$1,420 / coastalclimatecontrol.com	$1,345 / seafrost.com

★ Best Choice ✓ Recommended

*The Frigoboat Capri 35F was tested in both auto and manual modes.

Each kit had various controllers to regulate the compressor RPM. Testers used the automatic or default settings for the Adler Barbour and Sea Frost fridges. The manual Frigoboat controller was fixed at the typical setting for the task being evaluated.

factors can challenge a reefer system's capacity. Dometic uses only the BD50F, believing that the 25-percent increase in capacity offsets its decrease in its overall efficiency.

The Danfoss controller offers several new features. Perhaps the most interesting is Automatic Energy Optimizing (AEO)—a smart controller relay that automatically changes the compressor's RPM based upon running conditions. The RPM "soft starts" at a slower RPM, then ramps up based upon an algorithm that adds 400 RPM every 12 minutes until the unit either reaches 3,500 RPM, or cuts off after reaching its thermostat setting. The reasoning behind this gradual start is that it makes more efficient use of cooling capacity, but under higher heat loads, the unit automatically ramps up to its maximum RPM.

In our test unit, the larger Danfoss BD50F compressor was teamed with a larger evaporator (VD-152) that provided increased cooling surface area, so this system was able to drop the box temperature a little more quickly than its competitors, but it also demonstrated an increased appetite for amp-hours.

Sizing the evaporator to match the box is important, but it is just as critical that the evaporator matches the output capacity of the compressor. Adler Barbour carefully pairs up its hardware for optimum performance. The larger BD50F compressor is also offered by both Frigoboat and Sea Frost. This compressor is a good fit for boxes over 8 cubic feet or for boats cruising tropical climates, but its greater cooling capacity comes with increased power consumption. The laws of physics allow no free lunches, something worth keeping in mind when comparing these products.

The simplest and most common form of thermal control is the conventional mechanical thermostat, a switching device that uses a probe sensor (gas-filled tube) and a diaphragm-type, mechanical on/off relay. This analog function allows users to select a "general" turn-on and turn-off point to keep the box cycling within a few degrees. We found that these reliable but rust-prone mechanical thermostats could be set to cycle within the 39- to 42-degree range. Over the years, the galvanized mild-steel sheet metal in these thermostats corrode, but they often outlast the evaporator units they regulate.

There were a few construction details that testers didn't like about the new Cold Machine. The first was the one-time-only nature of the self-sealing connectors. Once made fast, the compressor and evaporator components cannot be disconnected without losing the refrigerant. Other systems had more expensive resealable fittings that allowed the components to be disconnected without losing their charge, a feature that adds greater flexibility for the do-it-yourselfer. Also, among the three systems scrutinized, the Cold Machine's tube soldering showed the most oxidation, due to what appeared to be a lack of quality control. This may be isolated to our particular unit, but it stood out. Lastly, the connector for the thermostat circuit used the RJ-11-type "telephone" plug to connect the control unit to the compressor. No matter how well you protect this socket, this is a poor connection for the marine environment. Despite these few shortfalls, the system performed flawlessly, offered more capacity than its competitors, and was competitively priced, keeping it in close contention with the others.

Bottom line: The Cold Machine is a good pick for sailors who can live without modest gains in energy efficiency, particularly those with a bigger box, or a less-than-perfect environment for cooling. Its connectors and tubing hold it back in terms of construction quality and user-friendly installation.

FRIGOBOAT

Compact, efficient, and extremely well made, the air-cooled Capri 35F squeaked ahead in our tightly competitive group of three. The system is a good example of component miniaturization with a bent toward efficiency.

The Danfoss BD35F compressor, control unit, fan, and condenser fit on a 10-by-8.25-inch stainless-steel tray, and offered the smallest footprint of all the units test-

HOW WE TESTED

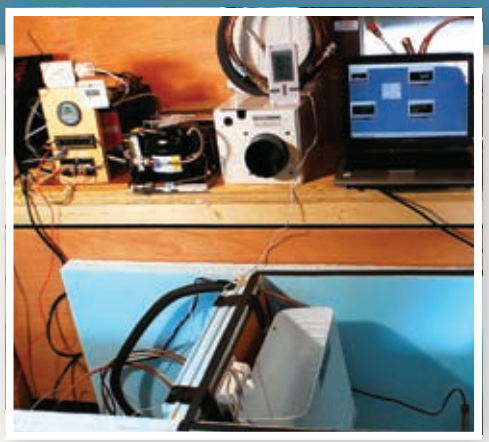
A Chilling Task: Measuring Efficiency

For this test, *Practical Sailor* constructed an 8-cubic-foot box in which each of the three units were tested. The efficiency, or lack there of, of the box, was meant to replicate an average, not-very-well-insulated ice box found aboard many production boats, new or old. These confines are often designed to maximize space at the expense of insulation efficiency. It would have been easy to construct a much more efficient box, but the data would have been less realistic.

We also controlled the power available to each system, mimicking a 200 amp-hour 12-volt DC battery bank that was fully charged prior to each test cycle. Volts, amps, and amp-hours were continually tracked through the use of a Link Pro battery monitor supplied by Xantrex. Using data sensors, a laptop, and data-logging software, we tracked the ambient temperature of the shop, and the temperature at the center of the box and in the machinery compartment where the compressor was housed. Run times were tracked, and physical conditions such as plate icing and the cut out/cut in times were monitored.

Ambient conditions at the compressor/condenser were controlled using a portable heater, and another small heater inside the box controlled temperature as well. Multiple sensors inside the box allowed for an average mid-box reading.

The ability to control and track the impact of heat inside the box and at the compressor kept the playing field even and allowed testers a chance to closely compare performance in the three.



Temperature sensors fed into data-logging software on a laptop to chart cooling efficiency.

The first performance test measured the amount of time and amp-hours required to cool a 60-degree box down to 40 degrees. The second test measured the amount of energy required to maintain the box at 40 degrees for 12 hours, with ambient temperatures at 60 degrees. Cooling capacity was tested by cooling a 90-degree gallon jug of water down to 42 degrees, tracking both time and energy consumed in amp-hours.

ed. The rectangular evaporator bin can be tucked neatly into a small 2.5-cubic foot reefer/freezer and is also rated for boxes as big as 10 cubic feet.

One of the features we liked most was the manual mode, an option that lets the user select the most efficient, low-power setting (2,000 RPM), delivering the highest COP. This setting, which runs the compressor at a slower speed but for a longer period, is useful for boats that depend on alternate energy sources such as solar and wind power. The rate at which amp-hours are depleted at this lower setting more closely matches the real-world outputs of onboard renewable energy sources. All the Danfoss units tested have the ability to be run at 2,000 RPM, but Frigoboat makes it easy to accomplish with the manual override Smart Speed Control (SSC), a simple circuit board attachment, or the AEO controller.

The large diameter stainless-steel connectors with O-ring seals proved to be user friendly, and required the lowest torque for tightening. This system, unlike the one used by Dometic, allows you to connect and disconnect couplings without any significant gas loss. The attention to soldering detail and care taken with the overall refrigerant plumbing was exemplary as was the overall design of the system.

The evaporator frosted up in the shortest period of time and even when running on the "high" RPM setting, the return tube did not show signs of frosting, two indicators of a properly charged system. The aluminum evaporator bin is not rugged, but as demonstrated by the 10-year lifespan of similar technology, the efficient cooling surface is appropriate for the job at hand.

Our most significant complaint about the Frigoboat related to the overlap length of the small ⅛-inch copper tubing that was much longer than the ¼-inch return line. In order to connect it to the compressor, a very careful curve had to be made, avoiding any kink or restriction in the thinner tubing. The purpose of the different lengths of tubing is to allow a more compact cluster of couplings when it comes time to press or pull the tubing through a conduit or tight confine. In this case, a good idea was simply overdone, in our opinion.

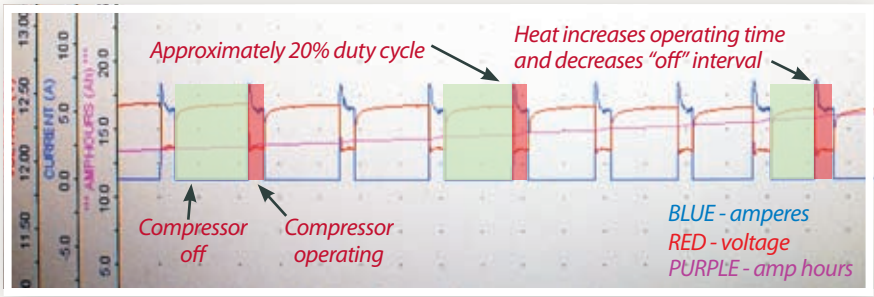
During our testing, we used Frigoboat's standard mechanical thermostat. This worked quite well, but it was not as efficient as the optional digital model. The latter allows for more precise cut-in and cut-out temperature control. We found the Smart Speed Control to be very useful, allowing us to shape the unit's current demand based upon cooling needs as well as battery condition. For example, when the charge was diminished (battery voltage under load at around 12.1 volts DC), switching to the 2,000 RPM setting not only gave us the highest COP, but the fridge's low 2.9-amp current draw extended the discharge capability of the battery bank.

Bottom line: Test results in the Value Guide on the adjacent page speak for themselves, underscoring that the Capri 35F is both efficient and packs quite a bit of capacity in a small package. It also ranks high with regard to attention to details and construction quality.

SEA FROST

The 12-volt DC, air-cooled BD plate system from Sea Frost that we tested uses a Danfoss BD50F compressor the company tucks into a powder-coated alloy box. The compact box protects components and provides efficient ducting for the fan.

Sea Frost founder and owner Cleave Horton prefers to pre-set the BD35F to its highest capacity 3,500 RPM run mode. This is accomplished by adding a 1,500-ohm resistor to the thermostat circuit. It's



The graph above shows how the compressor reacts when heat is added. The compressor turns on more frequently and stays on longer, consuming more amp-hours. Frigoboat's manual controller (immediate right) and Smart Speed Control (far right) proved helpful to maximizing efficiency.

Achieving Energy Independence

Bob Williams, the electrical wizard of Sea Air Land Technology (SALT), once said that, "refrigeration problems usually need an electrical system solution." Williams advises any boater considering a major equipment upgrade to do an energy audit, a simple amp-hour tally based upon the current draw of each electrical item and how much time it will actually operate over 24 hours. The sum reveals what the house battery bank must daily supply in order to make all gadgets function according to plan. The owner of a classic cruiser may get away with a paltry 50 or 60 amp-hours, while its modern counterpart may gobble up over 200 amp-hours a day. The bottom line is that there's no free lunch, and when adding refrigeration and other gear, check what it costs in amp-hour as well as dollars.

Here are some of William's other tips to ensure an energy-efficient upgrade:

• Always opt for heavier gauge wire to minimize voltage drops and make sure to use top-quality connectors that are carefully crimped and protected from moisture.

• Paralleled house batteries should be "from the same litter"— meaning the same brand, size, and date of purchase. In cases where paralleled batteries are being charged by either an alternator or charger, introduce the positive and negative leads at opposite ends of the paralleled batteries.

• If you opt for a high-output alternator, make sure that the belts and brackets can stand up to the loads. Double belts need very stable bracketing.

• Don't use high-output alternator belts to drive coolant pumps because of the heavy, seal-damaging side loads that they impart on the pump.

• Some modern regulators for high-output alternators (like those from Balmar and Ample Power) offer further protection from mechanical loads by gradually ramping up alternator output, and monitoring the temperature of the battery cases and alternator frame. Many also include limiting features that allow a user to reduce the maximum output, a feature that can pay off in alternator longevity.

• Effective insulation, well-gasketed lids, and keeping the box's interior volume to the minimum required offer the potential for great energy savings.

• Finally, a large house battery bank, 400 amp-hours or more, and an ability to add copious amps when the engine is running, beef up the power production and storage side of the equation. Add a high-output wind generator and some solar panels, and when diesel prices resume their climb, you can toast your newly engineered immunity with a cold beverage.

a Danfoss-approved modification. The upside is more capacity while the downside is a lower COP.

The Sea Frost system uses a half-inch-thick stainless-steel cold plate-style evaporator rather than the more common pressed aluminum evaporator. Both approaches handle the evaporation portion of the cooling cycle, providing surface area where a cold metal can come into contact with warmer air and allow thermal transfer to take place. Another design difference in the Sea Frost system is that the liquid refrigerant squirts through a more efficient expansion valve rather than a simple capillary tube. The drop in pressure at the expansion valve allows the liquid to become a gas, and the cooling process begins. In either type, the more refrigerant you have changing state and the more evaporator surface available, the more effective the system will be.

A look at evaporator efficiency offers a quick lesson in thermodynamics. Testers were interested in how the stainless-steel plate stacked up against the alloy box-type evaporators used by Sea Frost's competitors. A look at the thermal conductivity of metals shows aluminum as more efficient, but Sea Frost contends that because of the slow rate of heat transfer, this is not significant. In addition, the softer aluminum is more prone to damage from blows, corrosion, or an ice pick. So despite its efficiency handicap (as measured in amp-hours), the durable stainless-steel evaporator plate ranks high for user friendliness.

Sea Frost adds value with its close attention to details such as high-quality Aeroquip self-sealing connectors, carefully silver-soldered joints, and the component protection afforded by an enclosed, well-ducted compressor. The stainless-steel evaporator plate comes with spacers for mounting it just off the box wall, leaving the internal space of the ice box well preserved.

The efficient Danfoss BD50F is wired to run full-bore at 3,500 RPM, but the AEO controller protects against overload and under-current operation. Unfortunately, the efficiency of the 2,000-RPM low-current demand cycle is not available with the manual thermostat or with the optional electronic thermostat and thermometer. However, the latter offers precise cut-in and cut-out temperature control that can

A CLOSER LOOK

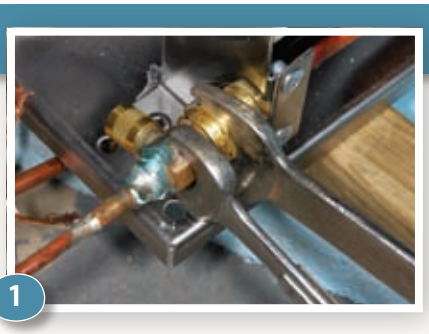
Tube, connector, and wiring details revealed some of the more obvious differences in the construction quality of the refrigeration units we tested.

1. Soldered unions on the Adler Barbour showed signs of corrosion and, once installed, could not be removed without refrigerant replacement.

2. The Adler Barbour uses the undesirable RJ-11-type plug to connect the thermostat to the control unit.

3. The Sea Frost system uses an expansion valve to meter the pressure of the liquid refrigerant entering the evaporator plate.

4. The well-made unions on the Frigoboat system could be taken apart without requiring a complete recharge.



1 *Adler Barbour CU-100*

2 *Adler Barbour CU-100*

3 *Sea Frost BD*

4 *Frigoboat Capri 35F*

help reduce unnecessary running time.

A manual throttle up/throttle down effect can be achieved through the use of Sea Frost's BD Speed Control, a three-position switch that changes the resistance in the thermostat circuit. The result is an RPM selection (low, medium, high) that includes the extremes and midpoint of the 2,000- to 3,500-RPM operating range. With zero ohms of resistance, the RPM stabilizes at about 2,000 RPM, and this low speed offers the least cooling capacity, but the highest energy efficiency. A 1,500-ohm resistance placed in the thermostat circuit delivers just the opposite effect. The specified COP identifies the most effective setting for energy efficiency (2,000 RPM), however, it involves longer run times and a lower rate of BTU removal.

Keeping the duty cycle under 50 percent is important, especially with a BD50F compressor at full RPM. Heat, in the ice box as well as in the compressor space, is the system's enemy. And in larger, less efficient ice boxes, there's always the opportunity to step up to the increased capacity of Sea Frost's BDxp unit, with a larger plate, two plates, and/or a water-cooled condensor.

Bottom line: The Sea Frost BD system is a well-made alternative to the alloy evaporator system. The builder has taken extra steps to keep the delicate fins of the condenser well protected and offers an attractive, and ruggedly fabricated stainless-steel evaporator that's proven to outlast alloy bins or plates.

CONCLUSIONS

This test targeted three of the most respected manufacturers in marine refrigeration systems, each capitalizing upon advances in the Danfoss compressor. During testing, we quickly saw that each of these three systems were capable of many years of good performance.

To a great extent, individual needs will guide selection. For instance, if the bottom line is energy efficiency and the ability to cool a small, well-insulated box with the least amp-hours possible, Frigoboat's Capri 35F gets the nod. If sheer ruggedness is important, Sea Frost takes the lead. Finally, those with a larger ice box planning to cruise in a sweltering climate may be better off with the more powerful BD50F compressor and large evaporator that comes with the Cold Machine.

The Frigoboat's Best Choice rating is due in large part to its amp-miser efficiency and compact size. Another big plus was the simple power management system that came with the remote manual/auto control, allowing crew to pick an operating RPM (capacity) so that when the engine was running, the alternator's excess power could be used most efficiently. And during the night, when power reduction was a big plus, the 2,000 RPM run speed would maximize the COP.

Testers found Sea Frost and Frigoboat neck-and-neck in quality control and attention to detail. Frigoboat also offers stainless-steel plates, an efficient keel cooler, and several remote digital thermostats/controllers. However, it wasn't these features that clinched it. Instead, it was a combination of efficiency, reliability, and capacity that gave line honors to the Frigoboat.

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